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VEGETATION PATTERNS AND BASIN MORPHOMETRY OF A NEW ENGLAND MOAT BOG

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ABSTRACT

We describe the relationships between vegetation patterns, depth of sediment accumulation, and distance to shore in Arcadia Bog, a small moat bog in Belchertown, Massachusetts. A Fringe Moat community occurs primarily where sediment depths are 0–2 m and at 0–10 m from shore. Shrub Thickets are least restricted in their distribution, occurring at 0–30 m from shore above 0–10 m of sediment. The true bog community (Dwarf Tree/Shrub) is divided into two types—Tamarack/Spruce centered at 15–25 m from shore above 7–11 m of sediment and Spruce/Tamarack at the deeper, more distant central portion of the basin (20–40 m from shore, 10–13 m depth). This community is uncommon in central Massachusetts. Variations in surface-water pH suggest that the distributions of at least some species may be influenced by nutrient availability. Additional studies would be required to determine the relationship between physiographic location and water chemistry and flow, the ecological factors most likely controlling vegetation patterns in Arcadia Bog.

Key Words: wetlands, moat bogs, vegetation classification, ordination, central Massachusetts

INTRODUCTION

Much of the literature of peatlands relates to northern mires of types that, except for Maine, are not widespread in northeastern United States. A number of authors have described the vegetation patterns of peat bog-lake systems (Vitt and Slack, 1975; Dunlop, 1987; Damman and French, 1987), but few satisfactory interpretations of the factors responsible for vegetation distribution in these peatlands have been developed. This study was undertaken to determine the relationship between vegetation patterns and physiographic characteristics of Arcadia Bog, a small moat bog (*sensu* Damman and French, 1987) in central Massachusetts. An understanding of this relationship could be helpful in identifying fundamental environmental factors controlling vegetation patterns within bogs of this type.

Early investigations of bogs focused on the influence of hydrarch succession on vegetation patterns (Clements, 1916) and the importance of physical factors as they affect basin filling and bog-margin development (Shaw, 1902). Although plant succession may influence current vegetation patterns (Swan and Gill, 1970), vegetation zonation in peat bogs may remain fairly stable in the absence of changes in hydrology (Damman and French, 1987). In such instances, chemical and hydrologic factors may be significant in determining vegetation patterns. Kratz and Dewitt (1986) described the processes influencing peat accumulation in bogs similar to Arcadia Bog, but they did not discuss implications for vegetation patterns. Damman and French (1987), drawing on the work of Damman (1978), Ivanov (1981), Ingram (1984) and others, indicated that water chemistry and water levels control vegetation patterns in peat bogs. In field work reported here, we examine the relationship between vegetation zones and basin morphometry (depth of organic sediments and distance to shore); it is useful to determine the relationship between vegetation zonation and basin morphometry because factors influencing vegetation development may vary predictably with location within a bog.

GENERAL SITE DESCRIPTION

Arcadia Bog is southeast of Arcadia Lake in Belchertown, Massachusetts [southeastern corner of the Belchertown Quadrangle (U.S.G.S. 7.5 min. series, no. N4215)]. The bog and nearby kettle-hole lakes lie in an area underlain by glaciofluvial deposits (mostly sand and gravel) with a general southwestern drainage pattern. These kettle-hole depressions overlie the Eastern Border Fault that separates the Connecticut Valley sedimentary formations (of Mesozoic age) from the Pelham Hills metamorphic formations (primarily gneiss and schist of Paleozoic age) (Caggiano, 1978, Ph.D. Dissertation, University of Massachusetts, Amherst). Drainage along the Eastern Border Fault may influence the hydrologic regime of the entire area, including the kettle-hole basins

(Motts and O'Brien, 1981). Large springs are reported in Arcadia Lake and other nearby lakes.

Stone and Borns (1986) suggested that deglaciation of central Massachusetts occurred as early as 14,000 to 15,000 B.P., although ice blocks apparently remained buried in the till and outwash after general glacial retreat. The presence of a deep-lying layer of forest floor material [including a white spruce (*Picea glauca* (Moench) Voss) cone recovered from 13 m below the surface] indicates that the ice block forming Arcadia Bog remained intact while vegetation colonized the soil above. Stratigraphy of a sediment core which we obtained indicated that after the ice block melted, the depression accumulated approximately 7 m of lake sediments; above these limnic sediments are 6 m of peat. Abundant *Ambrosia* (ragweed) pollen in the surface 25 cm suggests that this material was deposited since 1750 A.D., shortly after Belchertown was settled by Europeans.

Arcadia Bog has no channeled water inlet or outflow. Outflow from the basin may have been altered by the construction of a road on the south side of the bog, but we see little evidence that this construction substantially altered bog hydrology. Current water levels seem to reflect groundwater levels and the seasonal and periodic balance between precipitation and evapotransporation. The eastern edge of the bog is bordered by a steep slope, and the bog has a small watershed area with a ratio of the area of the watershed to the surface area of the bog of 1.3:1. Available plant nutrients in the bog are probably limited primarily to those being carried by inflowing water (from spring snowmelt, groundwater, and precipitation), to those entering in leaf fall from the upland or as dry fallout from the atmosphere, and to those made available by biotic agents (e.g., nitrogen fixation by blue-green algae, and "scavaging" by insectivorous plants such as *Sarracenia purpurea* L. and *Drosera rotundifolia* L.). A small section of the northern portion of the basin has been filled with refuse and is now overgrown with vegetation typical of disturbed areas in the surrounding uplands. We estimated the volume of fill to be 640 m^3, about 2% of the bog's total volume of approx. 30,960 m^3.

METHODS

A north–south baseline was established through the eastern part of the bog in 1985. East–west transects were established at 5 m intervals along this baseline. Depth probings were made with steel

Table 1. Vascular plant species list for Arcadia Bog, Belchertown, Massachusetts. Primary community affiliations are indicated for non-woody species.

Non-woody Species	Woody Species
Bidens sp. (Moat)	*Acer rubrum* L.
Calla palustris L. (several)	*Betula populifolia* Marsh.
Carex canescens L. (Moat/Shrub Thicket)	*Cephalanthus occidentalis* L.
Carex stricta Lam. (Moat)	*Chamaedaphne calyculata* (L.) Moench
Carex trisperma Dewey (Dwarf Tree/Shrub)	*Decodon verticillatus* (L.) Ell.
Drosera rotundifolia L. (Dwarf Tree/Shrub)	*Gaylussacia baccata* (Wang.) K. Koch
Eriophorum sp. (Dwarf Tree/Shrub)	*Ilex verticillata* (L.) Gray
Triadenum virginicum (L.) Raf. (Moat)	*Kalmia angustifolia* L.
Lycopus sp. (Moat)	*Kalmia polifolia* Wang.
Osmunda cinnamomea L. (Moat)	*Larix laricina* (DuRoi) K. Koch
Peltandra virginica (L.) Kunth (several)	*Lyonia ligustrina* (L.) DC
Sarracenia purpurea L. (Dwarf Tree/Shrub)	*Nemopanthus mucronatus* (L.) Trel.
Symplocarpus foetidus (L.) Nutt. (rare)	*Nyssa sylvatica* Marsh.
Typha latifolia L. (Moat)	*Picea mariana* (Mill.) BSP
	Pinus rigida Mill.
	Pinus strobus L.
	Pyrus arbutifolia (L.) Ell.
	Rhododendron viscosum (L.) Torr.
	Rhus vernix L.
	Sambucus canadensis L.
	Vaccinium corymbosum L.
	Vaccinium oxycoccos L.
	Vitis sp.

rods at sample points 5 m apart along the east–west lines. Each sample point served as the center of a circular plot of 2 m radius on which a relevé (Mueller-Dombois and Ellenberg, 1974) was sampled. Cover was estimated by assigning each woody species to one of the following cover classes: <1%; 1–5%; 5–25% 25–50%; and 75–100%. The average height of the dominant vegetation on the plot was also recorded. Sediment probing for the entire bog and vegetation sampling on the southern two-thirds of the bog were completed in February, 1986. Vegetation sampling of the northern portion of the bog was completed in March, 1987. Transect work was completed during the winter because of the difficulty associated with traversing the bog mat, much of which "floats," and the potential for damaging the vegetation in the process of carrying heavy equipment along closely spaced transects during the growing season. The bog was visited several times during the spring and summer of 1986 to record presence of herbaceous and low-lying species that were not evident during the dormant season surveys (Table 1). All but two of the 14 non-woody species we recorded appear to be largely restricted to vegetation types defined through analysis of the relevé data. On December 10, 1987 a portable meter was used to record pH values at a number of sample points in each of the vegetation zones identified from analyses of the vegetation data. Taxonomic nomenclature follows Gleason and Cronquist (1963).

An objective of our analysis was the delineation and evaluation of vegetation patterns in Arcadia Bog—patterns that are subjectively obvious but for which there exists no quantification with respect to vegetation structure, species composition or basin morphometry. Vegetation data generated from the relevés were analyzed using AGGLOM, a modification of Orloci's (1967) optimal agglomeration-polythetic clustering (classification) method, and DECORANA, a detrended correspondence analysis (DCA) ordination program (Gauch, 1982).

RESULTS

A bathymetric map (Figure 1) was developed for the bog, with 1 m contour intervals extrapolated between pairs of the 220 sample points on the grid. For mapping purposes, we assumed that the bog surface was level at approximately 100 m above sea level. Much of the bog mat floats, however, and its absolute height undoubtedly varies with seasonal changes in water level. We have not measured the extent of this variation.

Analysis of relevé data with AGGLOM defined five major groups or "clusters." Standardized and absolute Euclidian distance coefficients were used and produced similar groupings. Our interpretation is based upon the absolute distance analysis because it better utilizes our estimates of species cover. Community similarity indices were calculated to evaluate the similarity among vegetation groupings identified by cluster analysis (Table 2). We calculated three separate indices: Jaccard's which emphasizes species presence and total numbers of species; Sorensen's, which is similar to Jaccard's but places greater emphasis on species that recur in two communities than on those that are unique to one or another; and Spatz's, which incorporates an estimate of species abundances (Mueller-Dombois and Ellenberg, 1974). Two veg-

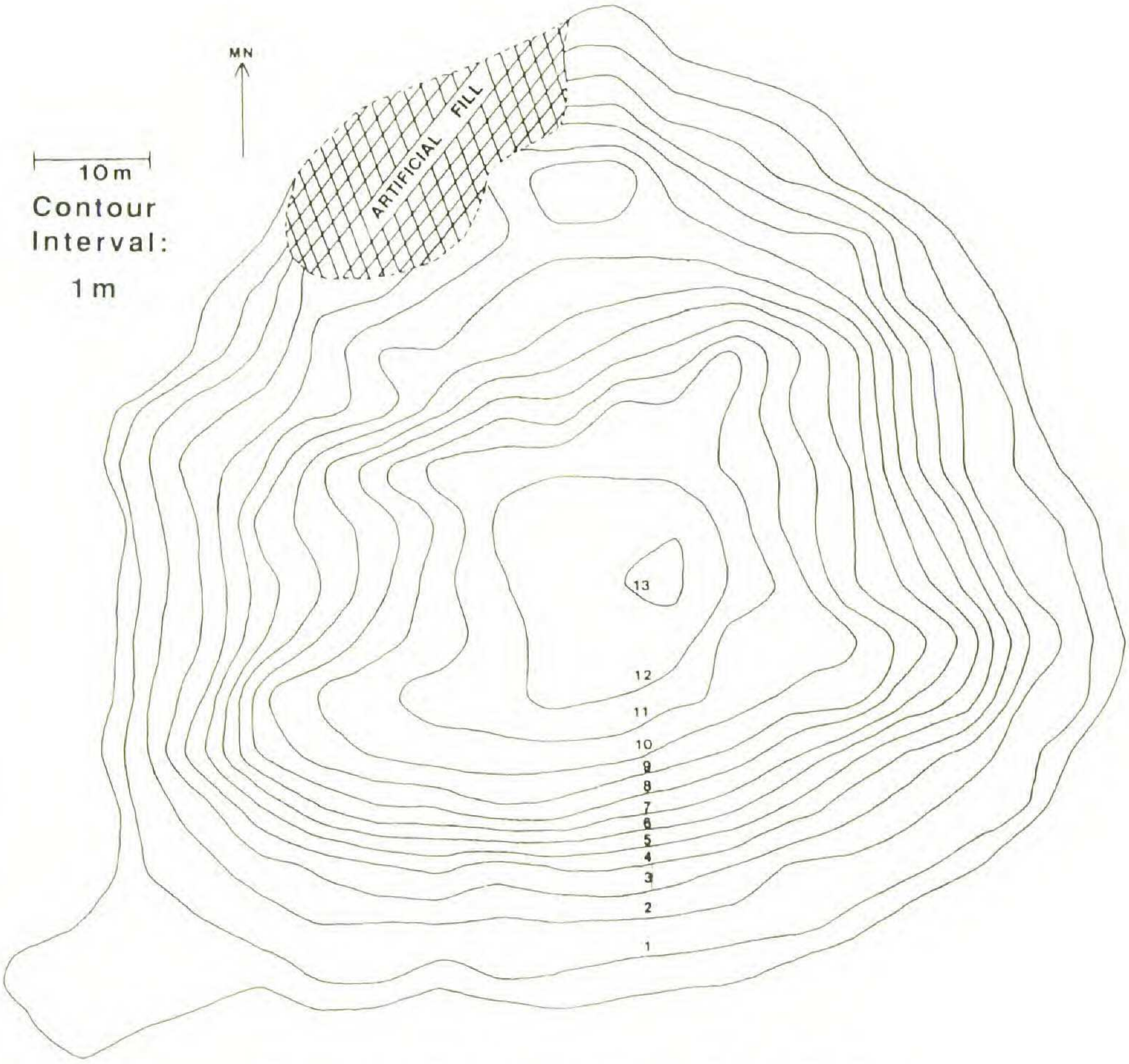


Figure 1. Bathymetric map of Arcadia Bog.

etation groups (IA2 and IB1) distinguished by cluster analysis have almost identical similarity indices (SI's) when compared with the other groups and have the highest SI's when compared with each other; in addition, they are not significantly different with respect to sediment depth or distance to shore. Therefore, we considered these two groups to be part of one broad Shrub Thicket group in defining vegetation communities and mapping their distributions on the bog.

Plotting DCA results revealed that for the first and second axes a number of sample points were high or low on the first axis and were strongly correlated with a defined cluster grouping (Figure 2). The Fringe Moat and Dwarf Tree/Shrub plots were removed, and the remaining Shrub Thicket and undefined plots were included in a second ordination according to the method of Peet (1980). This procedure facilitated a more detailed ordination of

Table 2. Similarity indices for vegetation groups identified by cluster analysis. [I.S.$_J$ = Jaccard's Index of Similarity; I.S.$_S$ = Sorensen's Index of Similarity; I.S.$_{Sp}$ = Spatz's Index of Similarity (after Mueller-Dombois and Ellenberg, 1974)].

Group Number (original groups defined by AGGLOM)	Similarity Index		
	I.S.$_J$	I.S.$_S$	I.S.$_{Sp}$
II vs. IB2	81.8	90.0	.38
II vs. IB1	69.2	81.8	.27
II vs. IA2	66.7	80.0	.21
II vs. IA1	50.0	66.7	.11
IB2 vs. IB1	84.6	91.7	.27
IB2 vs. IA2	83.3	90.9	.27
IB2 vs. IA1	64.3	78.3	.18
IB1 vs. IA2	84.6	91.7	.49
IB1 vs. IA1	78.6	88.0	.33
IA2 vs. IA1	64.3	78.3	.23
(After combining groups IA2 and IB1, with community designations in parentheses)			
II (Spruce/Tamarack) vs. IB2 (Tamarack/Spruce)	81.8	90.0	.38
II (Spruce/Tamarack) vs. IA2/IB1 (Shrub Thicket)	69.2	81.8	.24
II (Spruce/Tamarack) vs. IA1 (Fringe Moat)	50.0	66.7	.11
IB2 (Tamarack/Spruce) vs. IA2/IB1 (Shrub Thicket)	84.6	91.7	.27
IB2 (Tamarack/Spruce) vs. IA1 (Fringe Moat)	64.3	78.3	.18
IA2/IB1 (Shrub Thicket) vs. IA1 (Fringe Moat)	78.6	88.0	.28

similar plots, including the identification of additional Fringe Moat and Dwarf Tree/Shrub points (Figure 3).

Four vegetation communities and two transition zones defined by cluster analysis and DCA are as follows:

GROUP IA1—FRINGE MOAT COMMUNITY. Plots classified in this vegetation group have much standing water, only scattered, sparse vegetation, and occur at 0–2 m depth and 0–10 m distances to shore. Characteristic species include *Pyrus arbutifolia, Acer rubrum, Ilex verticillata, Decodon verticillatus, Rhododendron viscosum* and *Vaccinium corymbosum.* Absent are *Picea mariana, Larix laricina, Kalmia polifolia, Gaylussacia baccata* and *Pinus strobus.* See Table 1 for authorities of all plant names used in this paper.

TRANSITION ZONE 1 (TZ–1). This zone is intermediate between the Fringe Moat and Shrub Thicket. It has substantially

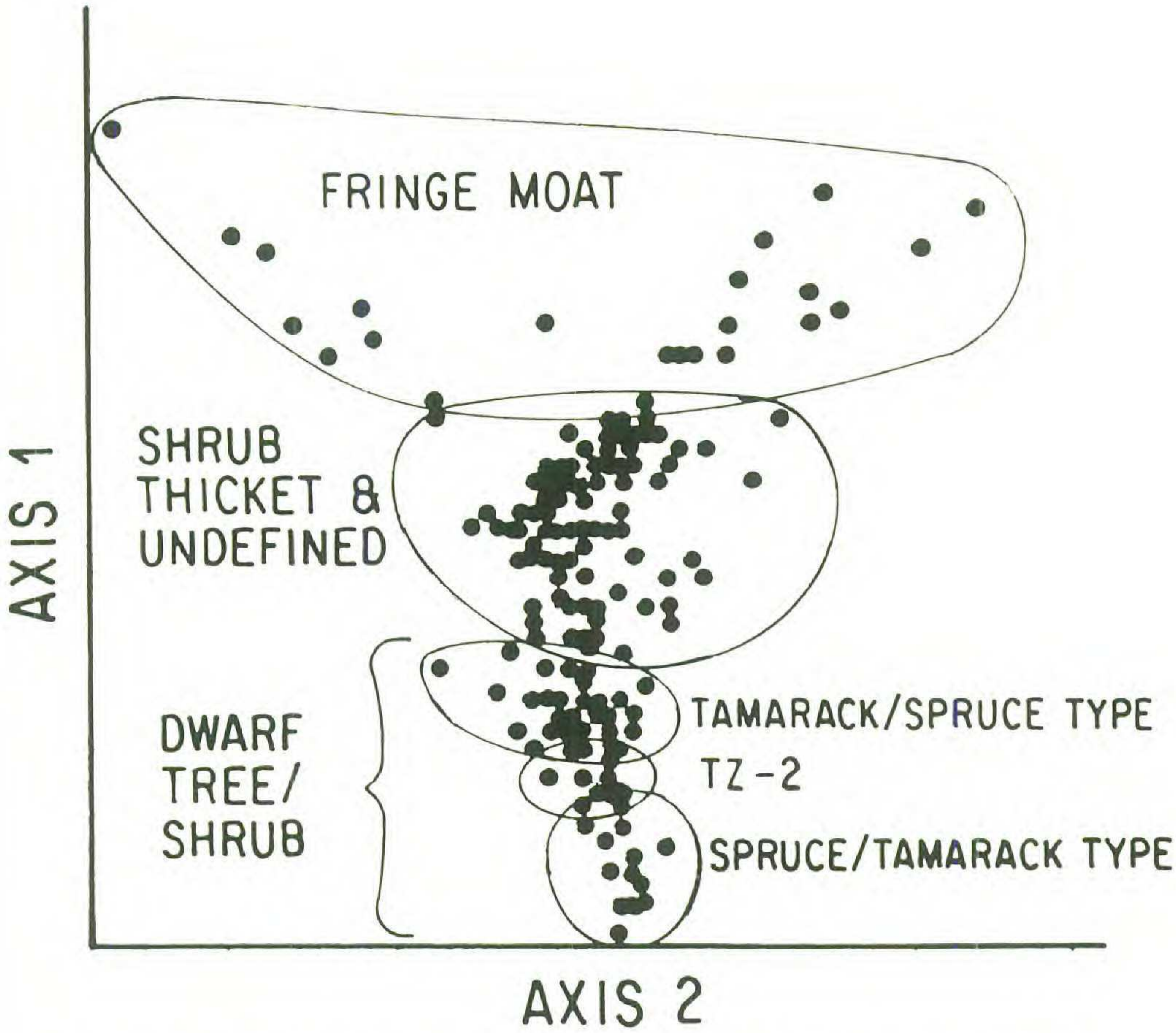


Figure 2. First ordination of relevé data from Arcadia Bog on the first two DCA axes showing the occurrence of sample plots which are related (along axis 1) to groupings identified by cluster analysis.

less *Kalmia angustifolia* than the Fringe Moat and no *Ilex verticillata,* but more *Lyonia, Pinus strobus, Acer rubrum,* and *Decodon.* There is less *Kalmia polifolia* and *Chamaedaphne* compared to the Shrub Thicket, and no *Picea, Larix* or *Gaylussacia.* Like the Fringe Moat, it has more *Pyrus* than the Shrub Thicket.

GROUP IA2/IB1—SHRUB THICKET COMMUNITY. This community is characterized by tall, dense shrubs and little open water. Plots extend across a wide range of depths (0–10 m) and distances to shore (0–30 m). *Rhododendron* and *Vaccinium* are the dominant plants, with *Pyrus, Gaylussacia, Kalmia angustifolia, Chamaedaphne* and *Larix* scattered throughout with low cover values. Absent are *Picea, Kalmia polifolia, Acer, Ilex* and *Decodon.*

GROUP IB2—DWARF TREE/SHRUB COMMUNITY (TAMARACK/SPRUCE type). Plots in this community have a continuous cover

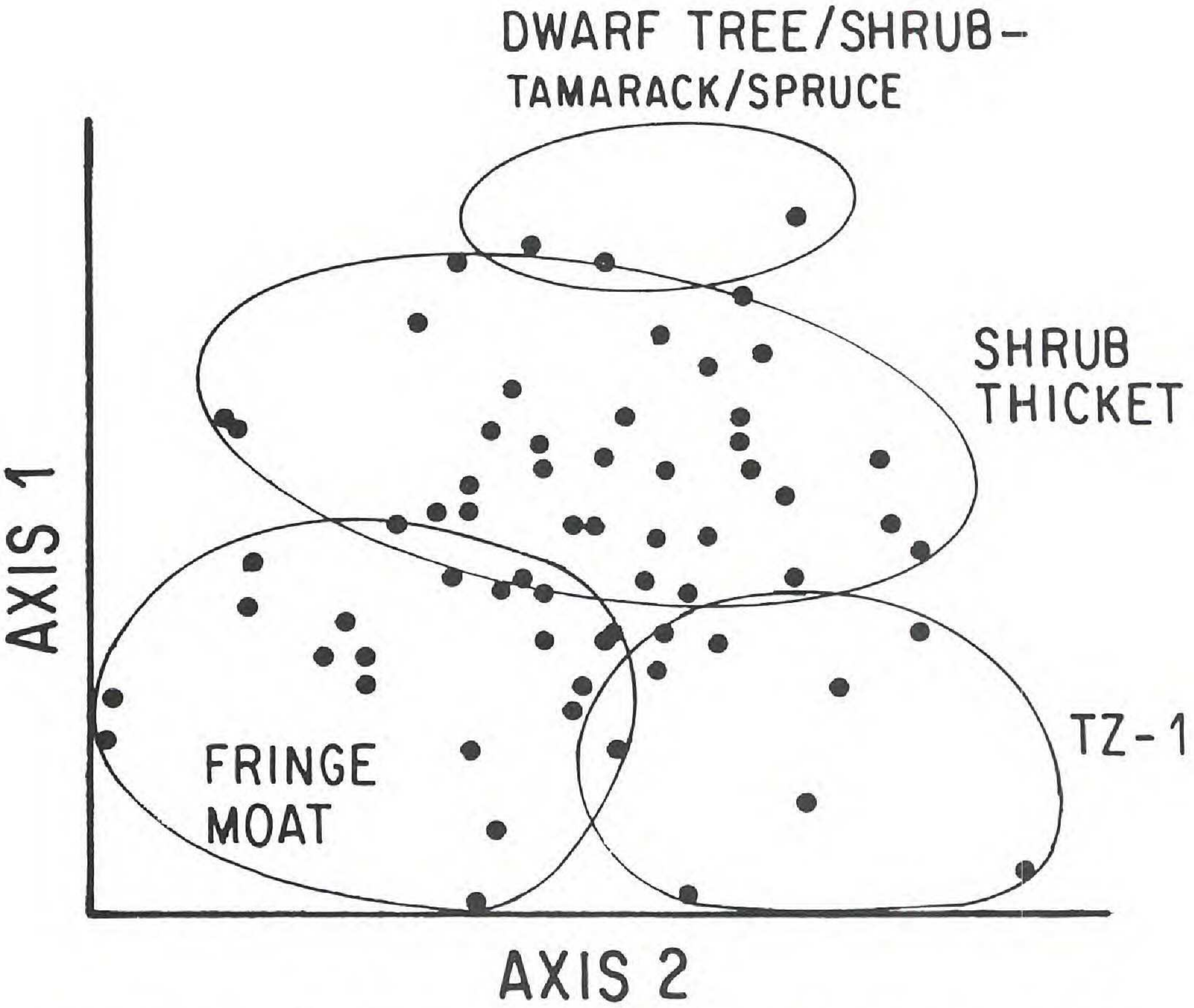


Figure 3. Second ordination of relevé data from Arcadia Bog, with Fringe Moat and Dwarf Tree/Shrub plots removed. Polygons encircle plots grouped as indicated by cluster analysis.

of *Sphagnum* spp., with areas of tall *Larix* (up to 5 m) and clustered *Picea.* The zone occurs at distances of 15–25 m from shore and at depths of 7–11 m. *Picea, Larix, Rhododendron, Vaccinium, Gaylussacia, Kalmia angustifolia* and *Chamaedaphne* are widespread in this vegetation group, with *K. polifolia* also present. Absent are *Pyrus, Acer rubrum, Decodon* and *Ilex.*

Transition Zone 2 (TZ-2). This zone has less *Larix, Kalmia angustifolia,* and *Pyrus* than the Tamarack/Spruce type and no *P. strobus.* It has less *Kalmia angustifolia* but more *Lyonia, Gaylussacia,* and *Acer rubrum* than the Spruce/Tamarack type.

Group II—Dwarf Tree/Shrub Community (Spruce/Tamarack type). This community occupies the central-most section of the bog. *Picea* attains its greatest frequency and cover here, as does *Kalmia polifolia.* This zone occurs primarily at depths of 10–13 m, 20–40 m from shore. *Picea, Larix, Chamaedaphne,*

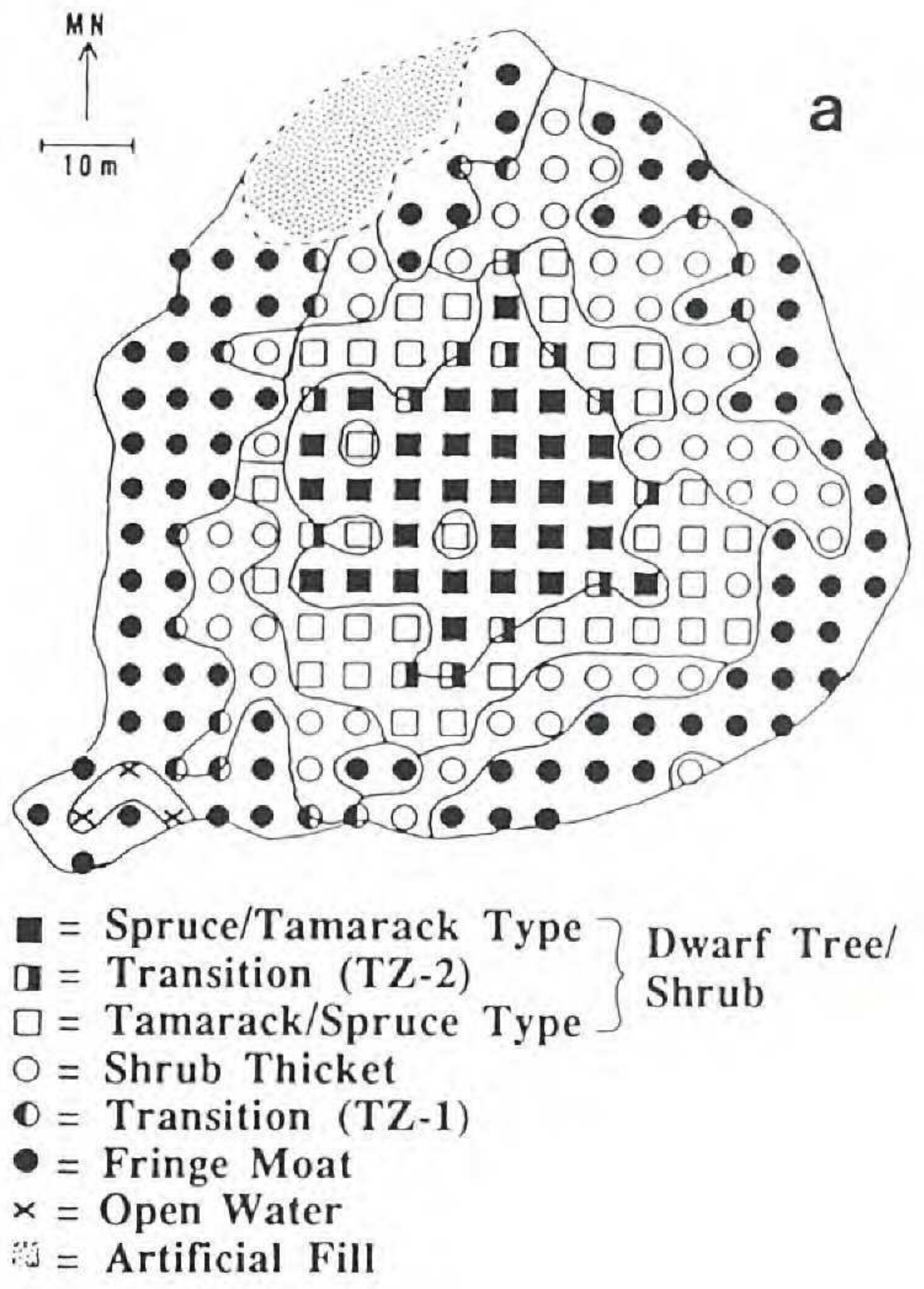
Table 3. Percent constancy within vegetation communities for woody species occurring in 217 relevés in Arcadia Bog (FrMo = Fringe Moat, ShTh = Shrub Thicket, T/S = Tamarack/Spruce, S/T = Spruce/Tamarack, TZ = transition zone).

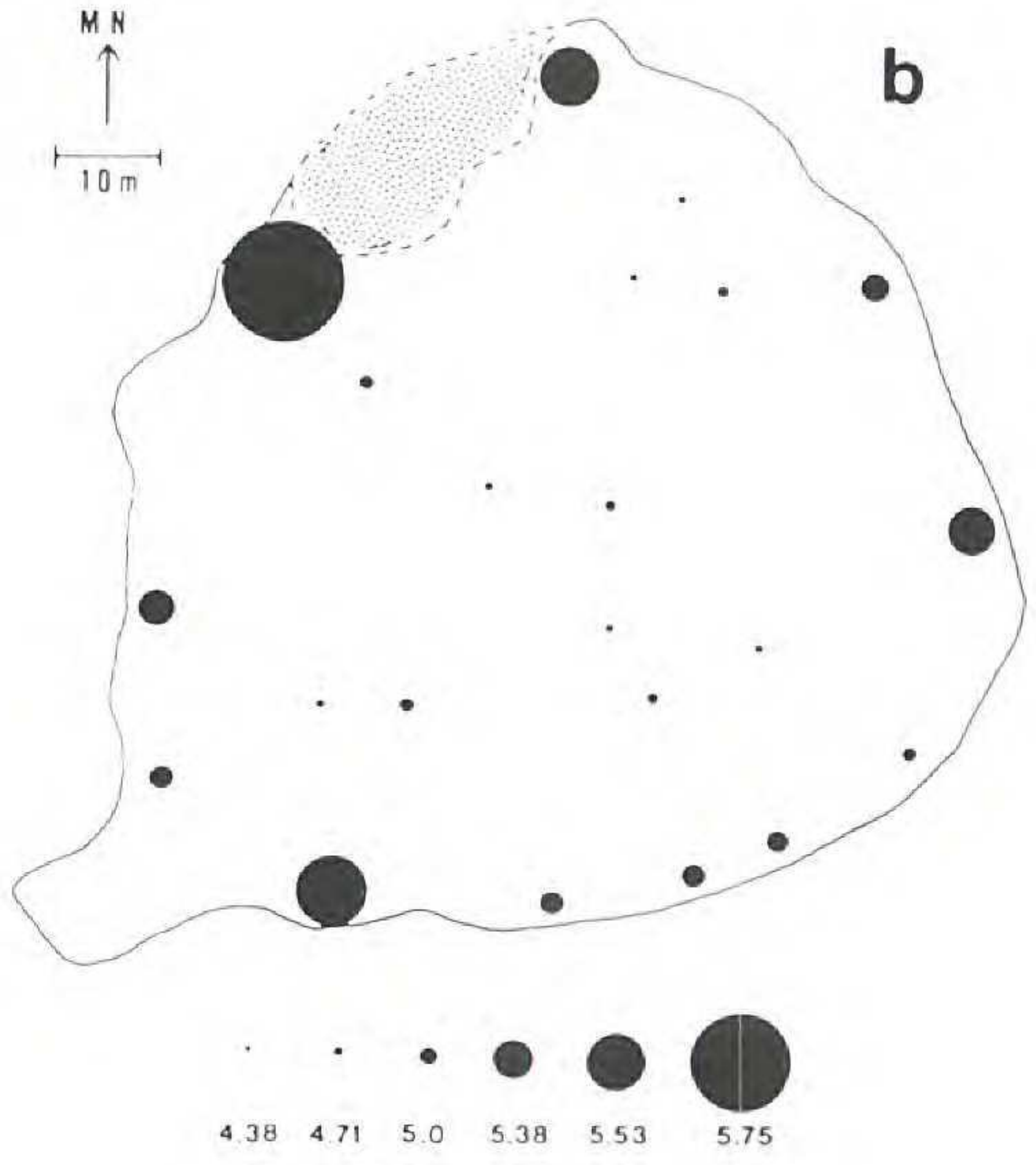
Species (see Table 1 for authorities)	Vegetation Community					
	FrMo	TZ-1	ShTh	T/S	TZ-2	S/T
Picea mariana	.0	.0	32.2	84.9	92.3	100.0
Larix laricina	4.94	.0	31.1	63.6	38.5	40.0
Rhododendron viscosum	75.3	100.0	97.8	81.8	76.9	73.3
Vaccinium corymbosum	91.4	80.0	100.0	100.0	84.6	73.3
Kalmia angustifolia	42.0	13.3	77.8	63.6	46.2	80.0
Kalmia polifolia	.0	6.67	20.0	72.7	84.6	83.3
Chamaedaphne calyculata	21.0	13.3	75.6	90.0	92.3	96.7
Lyonia ligustrina	2.47	20.0	13.3	24.2	23.1	3.33
Pyrus arbutifolia	72.8	86.7	48.9	18.2	7.69	.0
Gaylussacia baccata	.0	.0	46.9	78.8	76.9	50.0
Pinus strobus	12.4	40.0	48.9	18.2	.0	.0
Acer rubrum	12.4	40.0	31.1	12.1	15.4	.0
Decodon verticillatus	6.17	20.0	.0	.0	.0	.0
Ilex verticillata	16.1	.0	2.22	.0	.0	.0
Vitis sp.	4.94	.0	.0	.0	.0	.0
Cephalanthus occidentalis	3.70	.0	2.22	.0	.0	.0
Nemopanthus mucronatus	1.23	.0	.0	.0	.0	.0
Betula populifolia	2.47	.0	6.67	.0	.0	.0
Salix sp.	1.23	.0	.0	.0	.0	.0
Rhus vernix	1.23	6.67	6.67	.0	7.69	.0
Total Relevés in Community Type	81	15	45	33	13	30

Kalmia polifolia, Rhododendron, Vaccinium, Gaylussacia, and *Kalmia angustifolia* are the main taxa present in this vegetation group, with a marked absence of *Pyrus, Pinus strobus, Acer rubrum, Decodon* and *Ilex.*

The vegetation map (Figure 4a) was drawn using the results of the species ordination. Percent constancies for species within the six communities are presented in Table 3.

Canopy heights decline from the edge of the bog inward, with those at the center differing significantly from those in the Fringe Moat and Shrub Thicket zones (Table 4). The tallest trees in the bog are tamarack, which reach 6–8 m in the Shrub Thicket zone and about 5 m in the more central areas. A few black spruce within 10 or so meters of the edge of the bog reach 4–5 m, but





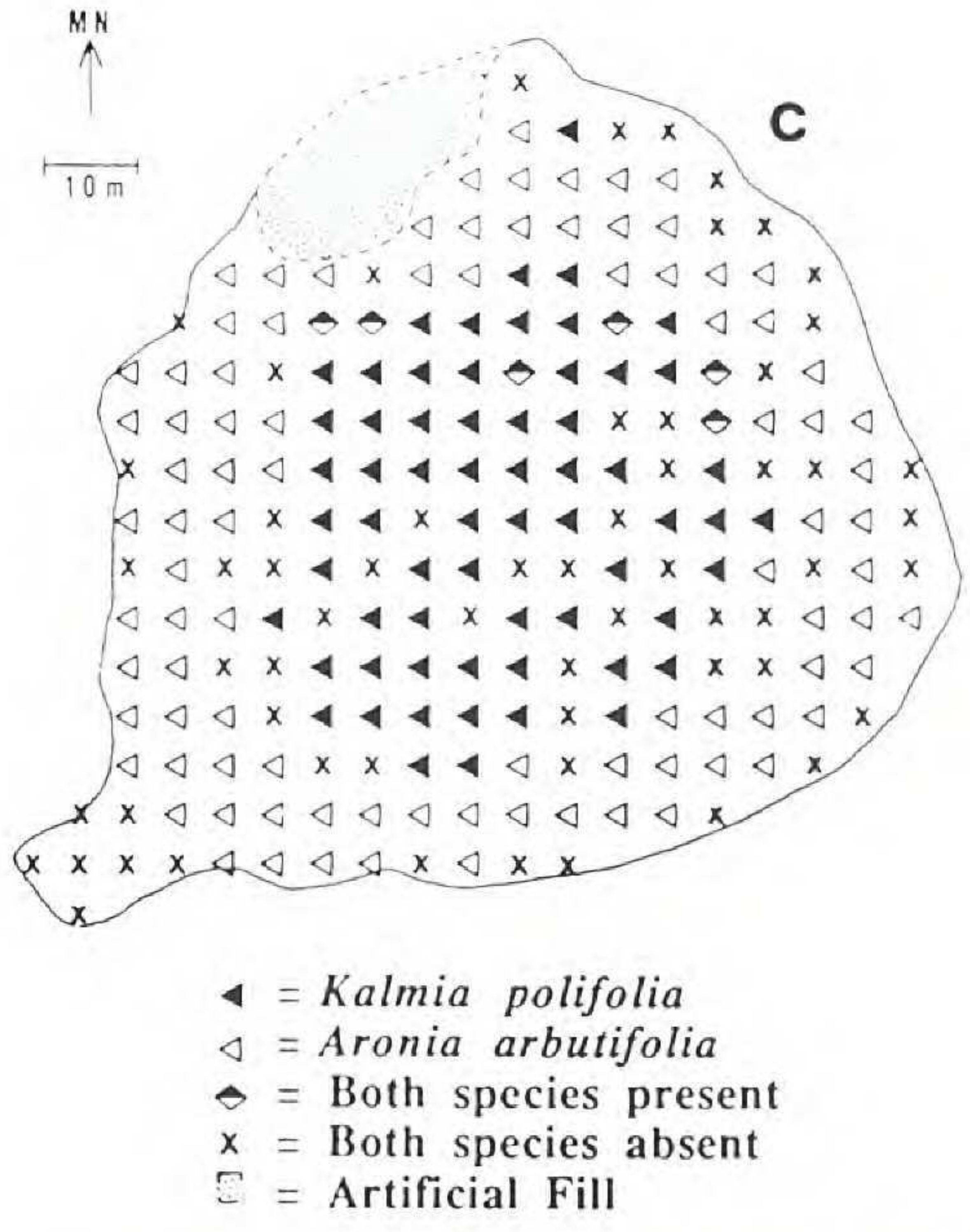


Figure 4a. Vegetation map for Arcadia Bog based upon the results of detrended correspondence analysis.

Figure 4b. Arcadia Bog pH values on December 10, 1987 for 22 sample points.

Figure 4c. Arcadia Bog distribution map of *Kalmia polifolia* and *Pyrus arbutifolia.*

none in the center exceeds 2.8 m. Most plants in the Dwarf Tree/Shrub community are a meter or less in height. Spruce were generally too small to age by coring, but we did section five stems growing in the central portion of the bog. There is a weak rela-

Table 4. Canopy heights by vegetation community type based on relevé data. Means followed by the same superscript are significantly different ($P < .05$). Data were unavailable for some relevés.

Vegetation Community	Number of Relevé's	Mean Height (m)	Range (m)
Fringe Moat	69	2.36^{a}	.60–3.50
TZ-1 (FrMo-ShTh)	13	2.42^{b}	1.10–4.00
Shrub Thicket	45	2.00^{ac}	.80–3.50
Tamarack/Spruce	29	1.50^{abcd}	.40–3.50
TZ-2 (T/S-S/T)	12	1.26^{abc}	.60–2.40
Spruce/Tamarack	30	1.04^{abcd}	.25–1.75

tionship between age and height ($r = .72$). Most stems taller than 1 m contain at least a few female cones and many stems smaller than 0.5 m appear chlorotic and in poor health. Dead spruce in the bog are generally 1–2 m in height.

Figure 5 presents the four vegetation groups and two transition zones discussed above as a function of depth and distance to shore. The Fringe Moat is generally restricted to the shallow portions of the bog which lie close to shore (mean depth = 1.4 m; mean distance to shore = 4.2 m). The Shrub Thicket occurs across a broad range of sediment depths (0–10 m) and distances to shore (mean depth = 4.2 m; mean distance to shore = 11.1 m). The Tamarack/Spruce type occupies the deeper portions of the bog with mean depths of 8.5 m and an average distance to shore of 20 m. Finally, the Spruce/Tamarack type is found in the section of the bog with the greatest accumulation of sediment (mean depth = 11.4 m) lying farthest from shore (mean distance to shore = 30.1 m). Chi-square tests comparing the number of sample points for each zone occurring at a particular depth indicate that there is a significant difference between the four primary groups ($P < .05$). The Tamarack/Spruce type has, in addition to widely scattered tamarack up to 5 m in height, fewer spruce than the Spruce/Tamarack type.

DISCUSSION

There is a clear relationship between vegetation zones, depth of sediment and distance to shore in Arcadia Bog. The vegetation patterns observed are similar to those described by Damman and

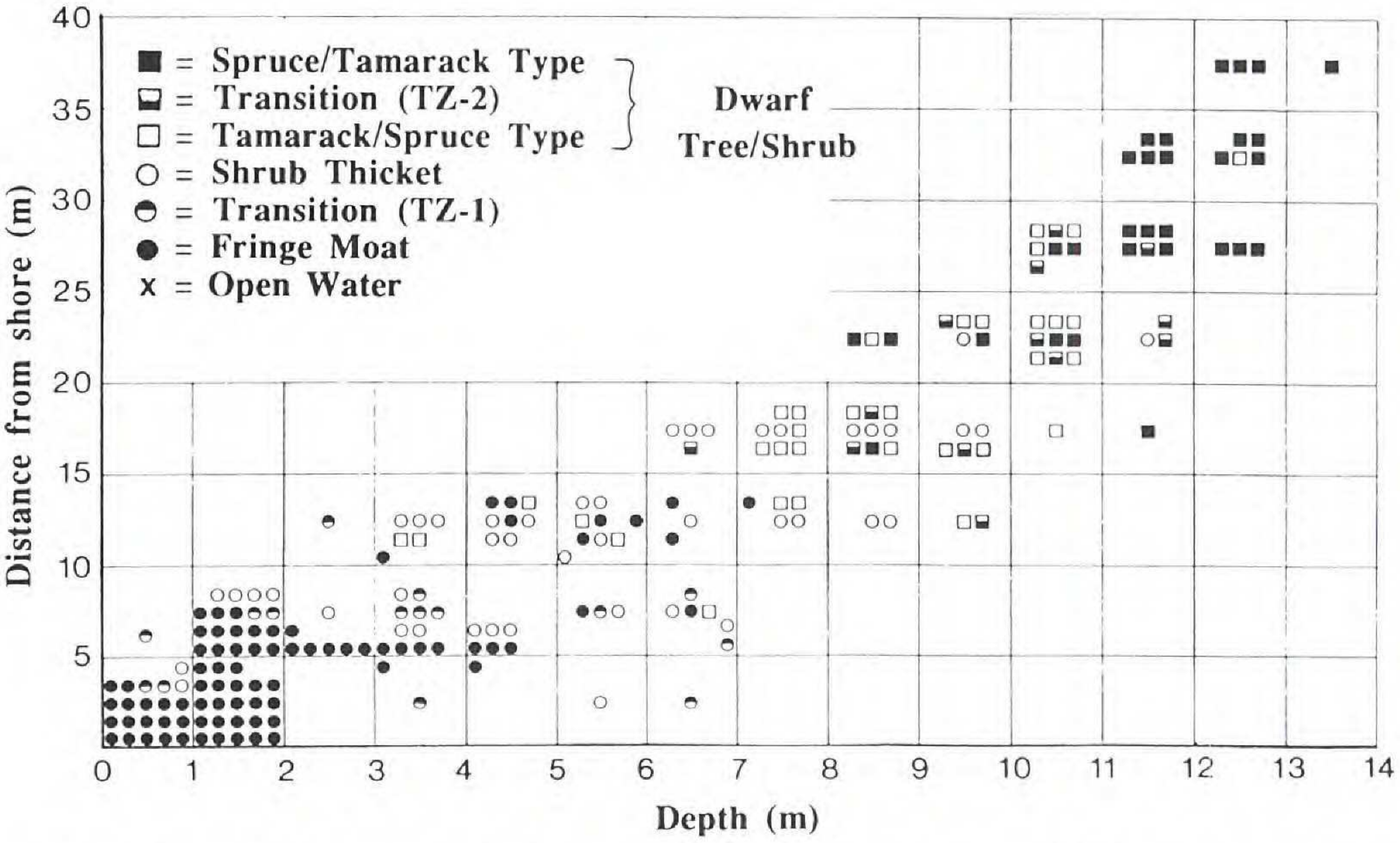


Figure 5. Distribution of vegetation plots by community and depth and distance to shore.

French (1987) as typical of moat bogs. A notable addition in Arcadia Bog is the well-developed Dwarf Tree/Shrub community in the center. The presence of a dwarf spruce community thus may reflect increasingly nutrient-poor conditions toward the center of the bog. Of interest is the presence in the moat fringe of certain species (*Typha* and others) more typical of eutrophic, marsh-like conditions. This association is not uncommon in moat-fringed bogs, which may occur in regions of large periodic (i.e., seasonal, annual or otherwise) water table fluctuations (Buell and Buell, 1975). The development of moat-fringed bogs is generally not well understood (Damman and French, 1987), although a number of hypotheses have been posed (MacMillan, 1894; Shaw, 1902; Buell and Buell, 1975).

Cluster analysis and DCA produced similar results; both identify Fringe Moat and central Dwarf Tree/Shrub communities (including, in the latter, Spruce/Tamarack and Tamarack/Spruce types). Classifying individual relevés using dendrograms generated by cluster analysis is sometimes difficult, however, since sample points which are similar in species composition and abundance may fall into separate clusters. Although these clusters (i.e., vegetation groups) may appear as distinct entities in the dendrogram, they may actually represent zones of transitional vegetation between truly distinct groups. Transition zones are to be expected because vegetation patterns reflect the differential responses of individual species to environmental gradients (Gleason, 1926; Whittaker, 1967). The results of DCA thus more accurately represent the gradational nature of vegetation variation than do cluster analysis results.

The distribution patterns of *Pyrus arbutifolia* (L.) Ell. and *Kalmia polifolia* are noteworthy. These species occur widely throughout the bog, but they co-occur in only six of 159 plots on which one of them occurs (Figure 4c). In Massachusetts *Pyrus arbutifolia* is most commonly found in swamps and at the edges of lakes, whereas *Kalmia polifolia* is generally restricted to nutrient-poor bog environments (Emerson, 1850). Their distributions at Arcadia Bog reflect these regional patterns, with *Pyrus* occurring principally near the bog margin and *Kalmia* occurring in the more central areas with lower pH values, suggesting that nutrient availability may be an important factor influencing the distribution of at least three species.

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